MASS DETONATION HAZARD ASSESSMENT

FROM VIOLENTLY DEFLAGRATING MUNITIONS

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MASS DETONATION HAZARD ASSESSMENT FROM VIOLENTLY DEFLAGRATING MUNITIONS

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ABSTRACT

We report on an investigation aimed at assessing whether the controlled, violent deflagration of Composition B loaded 105 mm shell can lead to the detonation of nearby rounds. Tests were grouped into 3 categories; single deflagrating donor - multiple acceptor arrays, projection of acceptor shell by a deflagrating donor and its impact on structural surfaces and multiple impacts causing transient interactions in acceptor shell. Trials were conducted with shell without boosters and fuzes, shell with boosters and plugs representing fuzes and recovered, damaged rounds.

Acceptors were recovered intact but with flattened faces and cracked fillings with no signs of reaction. No detonations were recorded. Separate experiments with single shell indicated that when low order reactions were deliberately stimulated in part of the filling then a deflagration to detonation transition could occur.

Consequently our results do not support the processes occurring in the deflagrating donor/acceptor tests as contributors to the mass detonation hazard of Composition B loaded 105 mm shell.

1. INTRODUCTION

Evidence presented by Frey et al [1] and Stosz [2] has shown that mass detonation can result from reactions other than the shocks generated by detonating donor rounds. Some of these events take several milliseconds [1] and are therefore not associated with shock initiation. The details of the origin and growth of these reactions are not understood. It is not surprising therefore that tracking down the causes of mass detonation in large munition arrays has proved difficult and has lead to the need to design simplified tests to evaluate candidate processes. To this end we have been investigating the likely consequences emanating from a donor shell undergoing a violent deflagration while positioned in various munition arrays. The arrays were designed to reproduce conditions encountered during munition storage and transport. Our investigation utilises a recently developed technique that allows the production of a controlled deflagration of a munition without the possibility of a transition to detonation invalidating the result [3].

Our aim is to investigate a range of munition types. The first part of the program has been undertaken using Composition B loaded 105 mm shell because of its availability and widespread use. Further testing is planned using munitions with thinner cases and a higher explosive charge / case mass ratio.

This paper presents the results of our investigation using 105 mm shell.

2. TECHNIQUE FOR PRODUCING CONTROLLED DEFLAGRATING DONOR SHELL

The technique for violently deflagrating donor 105 mm shell [3] consists of firing a shaped charge jet along the axis of the round with a velocity below the threshold to produce detonation of the filling. In this way the reaction produced in and behind the bow wave set-up in front of the penetrating jet sweeps through the length of the filling leaving no bulk explosive for a deflagration to detonation transition. Detonation does not result directly from the bow wave since the pressure-time profile is subcritical. Criteria for the jet initiation of explosive fillings has been discussed in detail elsewhere [4,6].

The application of the technique to a Composition B filled 105 mm HE M1 donor shell is shown in Figure 1 and summarised below.

The MRL 38 mm diameter shaped charge was used in the tests since there is a considerable data base on its effect on munition fillings [4-6]. This shaped charge contains a conventional copper liner with a 42° apex angle. The subcritical jet velocity was produced by firing the jet at 2 charge diameters' standoff through a steel barrier of appropriate thickness placed in contact with the shell case. The minimum thickness of the steel barrier (τ) was determined from the known critical jet velocity for the detonation threshold (V_j) using the Dipersio/Simon equation [7] to calculate the total thickness of steel required and subtracting the case thickness at the jet entry position;

$$\tau = s \left[\left\{ \frac{V_t}{V_j} \right\}^{1/\gamma} - 1 \right]$$

where s the standoff from the shaped charge to the top of the steel barrier,

V_t the velocity of the jet tip, and

γ the square root of the ratio of the steel barrier and jet densities.

For the 38 mm diameter shaped charge jet V_j was adjusted downwards to take account of the effect of the 105 mm shell side confinement on the Composition B filling, determined as 4.85 km/s [8]: this was equivalent to a total steel thickness of 72.5 mm. Since the thickness of the steel case at the jet entry position was 17.5 mm, a minimum of 55 mm of extra steel was required. The side confinement also holds the explosive together thereby assisting the deflagration process.

Characteristics of a deflagrating Composition B filled 105 mm shell that may be important in a mass detonation hazard assessment have been determined and are summarised below. Recovered fragments are shown in Figure 2 and were dispersed over an area of about 350 m radius. They are considerably larger and show different fracture patterns compared to those recovered form a detonating round , see Figure 3. The witness block under the nose of the shell exhibited no indentation but had the compressed remains of the booster can stuck to it. A detonation produced a well formed dent. Peak overpressure was measured at about 25% less than for a detonating round. High speed photography showed that initial shell burst occurred in the region of the driving band after an expansion of about 30% of a shell diameter (i:e 15 mm increase in shell radius).

Initial jet penetration velocities through the filling can be varied by adjusting the thickness of the added steel barrier on the base of the shell; the value selected for the tests was 3 km/s. Since the bow wave is coupled to the jet and reaction occurs within the bow wave, it is assumed that the deflagration velocity will have a similar value. This high reaction velocity and the characteristics measured above confirm that our tests are studying the effects from a particularly violent type of deflagration.

3. SINGLE DONOR-MULTIPLE ACCEPTOR TESTS

The direct effect of the expanding case, fragment impact and blast from a deflagrating donor round on adjacent shell was determined using the set-up shown in Figure 4. These tests were based on the methods used at BRL by Howe [9] for studying the effects of detonating donors. Acceptor standoff distances were 0,10,25 and 50 mm as measured from the driving bands. In some of the tests large fibreboard packs were placed 1 m from the shell for controlled recovery, in other tests the shell were recovered after free flight and impact with the ground. Tests were performed on shell with no boosters and fuzes (2 shots), shell with pressed flake boosters and plugs representing fuzes (PRF) (1 shot) and recovered, damaged shell (1 shot). Four shots were fired in which all acceptors were in contact with the donor.

A test was performed using the set-up in Figure 5 to assess the effect of shell jostling. The donor and row of acceptor shell were in contact and backed by a 25 mm thick steel plate and supporting sandbags.

In the tests in this and sections 4.0 and 5.0 the type of event was determined from witness block indentation, recovered fragment characteristics, impacted surface damage and in some tests, instrumentation records (overpressure, high speed photograph). Some donor rounds included probes on either side of the steel barrier as a check on the performance of the shaped charge jet. No substandard jets were detected.

All donor rounds deflagrated as planned. Recovered acceptor shell without the boosters and fuzes form the Figure 4 type firing set-up were flattened on the side adjacent to the donor, see Figure 6. Driving bands were either dislodged or distorted. Aluminium booster cans were crumpled but in position; when removed they showed that the filling was cracked without signs of reaction. The increased sensitivity of the filling to shock type stimuli was assessed by determining the critical jet velocity for the detonation threshold using the 38 mm diameter shaped charge. The critical value of 4.8 km/s compares to a value of 5.2 km/s for the undamaged material.

Recovered rounds with boosters and PRF exhibited similar damage with the addition that the plugs were bent, see Figure 7. Repeat firings using recovered shell produced cases with two flattered faces, no driving bands, dislodged or badly distorted booster cans and a filling with extensive cracking but no signs of reaction.

Acceptor shell from the shot where they were placed in a row (Figure 5) were recovered intact within 1 m of ground zero. The acceptor adjacent to the donor showed similar damage to that described above. The other acceptors showed progressively less damage as the original position moved away form the donor i:e the closer rounds appeared to act as a buffer for this type of impact.

The tests from this section suggest that the effect of case expansion, fragment impact and blast from a deflagrating Composition B loaded 105 mm shell can inflict severe damage on neighbouring rounds without being the direct cause of mass detonation.

4. ACCEPTOR SHELL PROJECTION AND IMPACT TESTS

These tests were undertaken to assess the hazard from the impact of projected shell on hard structural surfaces. A potential source for this type of event would be from a deflagrating donor shell ejecting neighbouring rounds when located in a munition stack during storage (temporary or permanent) and transport. Important structural surfaces would include concrete and steel.

The velocity of a projected acceptor from a deflagrating donor shell was measured at 40 m/s using multiple glass break screens [11]. This value is considerably lower than the critical fragment impact velocities of several hundred metres per second and upward reported by Howe et al [10] using a range of fragment sizes and Composition B with a steel cover thickness of 10 mm. The 105 mm shell case has a similar thickness along its central section. In our tests and for the type of event under study however the filling in the shell prior to impact would be damaged as a result of the deflagration projection process. This was shown in the examination of the fillings from the soft recovery tests described in Section 3.0 and critical jet velocity tests confirmed the accompanying increased sensitivity. A further feature of our tests is that the shell/target impact represents a fragment size beyond that reported in Reference 10.

The test set-up is shown in Figure 8 with the concrete target positioned 2 m from ground zero. Firings were undertaken with shell without boosters and fuzes, recovered damaged shell and shell fitted with boosters and a PRF. Separate tests were conducted with unboostered shell in which the concrete block was used to support a 10 mm thick steel plate.

All donors deflagrated as planned and projected rounds were recovered damaged but intact. Both the steel and concrete targets produced similar effects. The acceptor rounds had a flattened area on one corner with surface marks continuing along the length of the case. This type of corner-side slap on the target was compatible with the shape of the impression formed by the shell impact on the fibreboard packs in the soft recovery experiments reported in Section 3.0. Visual inspection showed the filling cracked but there was no signs of reaction. Rounds with a booster and PRF were likewise damaged plus the plug was bent. The experiment with damaged acceptors produced a second flattened face but the round remained intact; this retesting of damaged shell may be considered a worse case situation.

It is concluded that the projection of Composition B loaded 105 mm shell at velocities likely to be encountered from a neighbouring round undergoing a violent deflagration is unlikely to be the direct cause of a mass detonation. Our study has not addressed the impact of a shell projected by a detonating donor where higher flight velocities may be achieved.

5. TRANSIENT INTERACTIONS IN SHELL FILLINGS

Tests in this category were designed to assess weather transient interactions within the explosive filling would promote a deflagration to detonation transition (DDT). Such interaction may arise as a result of two rounds deflagrating either simultaneously or within a limited time frame of one another.

In the test shown in Figure 9 the central acceptor was subjected to the simultaneous impact from two adjacent deflagrating donors. For the set-up in Figure 10 two shell were deflagrated within a predetermined time interval. Thus the expanding case from the first shell deflagrated impacted on the second shell. The time delay was to allow the compression wave from the case impact to pass through the explosive filling and interact with the deflagrating front sweeping through the second shell. The concept is illustrated by the sketch in Figure 11. Experiments were conducted with time intervals of 16, 19 and 100 µs. For the shorter time intervals the deflagration fronts were calculated to be about 50 mm apart. Thus the effect of case interaction was expected to occur after both deflagrations were well established. Jet penetration equations and measurements [4,6,7] gave an estimated time for the jet to traverse the Composition B filling in the 105 mm shell of 92 µs. Consequently the 100µs time interval set between the deflagration of the two shell was designed to allow the compression wave resulting from case expansion and impact of the first shell to form a wide front prior to its interaction with the deflagration in the filling of the second shell.

The baffle in Figure 10 was designed to avoid the blast and fragmentation from the first shaped charge detonated moving the second shaped charge. Examination of the blast and fragment patterns on the walls of the baffle (they were symmetrical with respect to one another) and the jet penetration holes in the recovered steel barriers (central alignment and no key holing) indicated there was no interference between the shaped charges. This conclusion was supported by the Hycam photography records taken at between 35,000 and 40,000 pictures per second.

The central shell from the double, simultaneous impact experiment was recovered intact with two flattened faces, no driving bands and a cracked filling. Again visual inspection showed no signs of reaction. In the delayed interaction experiments all shell deflagrated without detonation occurring. Consequently these tests failed to provide any evidence that this type of transient interaction within the filling may be a contributing process to a mass detonation hazard of Composition B loaded 105 mm shell.

6. DEFLAGRATION TO DETONATION IN SINGLE SHELL TESTS

Other experiments investigating the response of Composition B loaded 105 mm shell to shaped charge jets have produced DDT. In these tests, jets with subcritical velocities (for detonation) in the range 2.8 to 5.0 km/s were fired across the diameter of the shell towards the nose end of the filling, but not close to the booster cavity. Four shots out of 12 produced a DDT at the base end of the shell - this was clearly evident from the changing indentation pattern along the steel witness plate. Penetration holes in the case from these jets are 10 mm diameter and less and hence the reaction stimulated by the jet cannot effectively vent. Consequentially the pressure build-up promotes a DDT in the large unconsumed mass of explosive towards the shell base. These results demonstrate that once a low order reaction has been stimulated in Composition B loaded 105 mm shell the potential exists for a mass detonation hazard. They further suggest that the impact and interaction processes in our tests did not produce the initial low order reaction.

7. CONCLUSIONS

Deflagrating donor, Composition B loaded 105 mm shell without boosters and fuzes did not cause the detonation of adjacent rounds in the following types of test;

- (a) single donor - multiple acceptor array
- (b) acceptor projection (at 40 m/s) and impact on concrete and steel targets,
- (c) simultaneous double impact on an acceptor,
- (d) interaction between two deflagrating rounds.

Trials using tests (a) and (b) with recovered, damaged shell and with shell containing boosters and plugs representing fuzes also did not produce detonations.

Consequently the processes in these tests are not supported as contributors to the mass detonation hazard of Composition B loaded 105 mm shell. Separate DDT experiments on single shell suggest this is because the impact and interaction processes did not produce the initial low order reaction.

8. ACKNOWLEDGEMENTS

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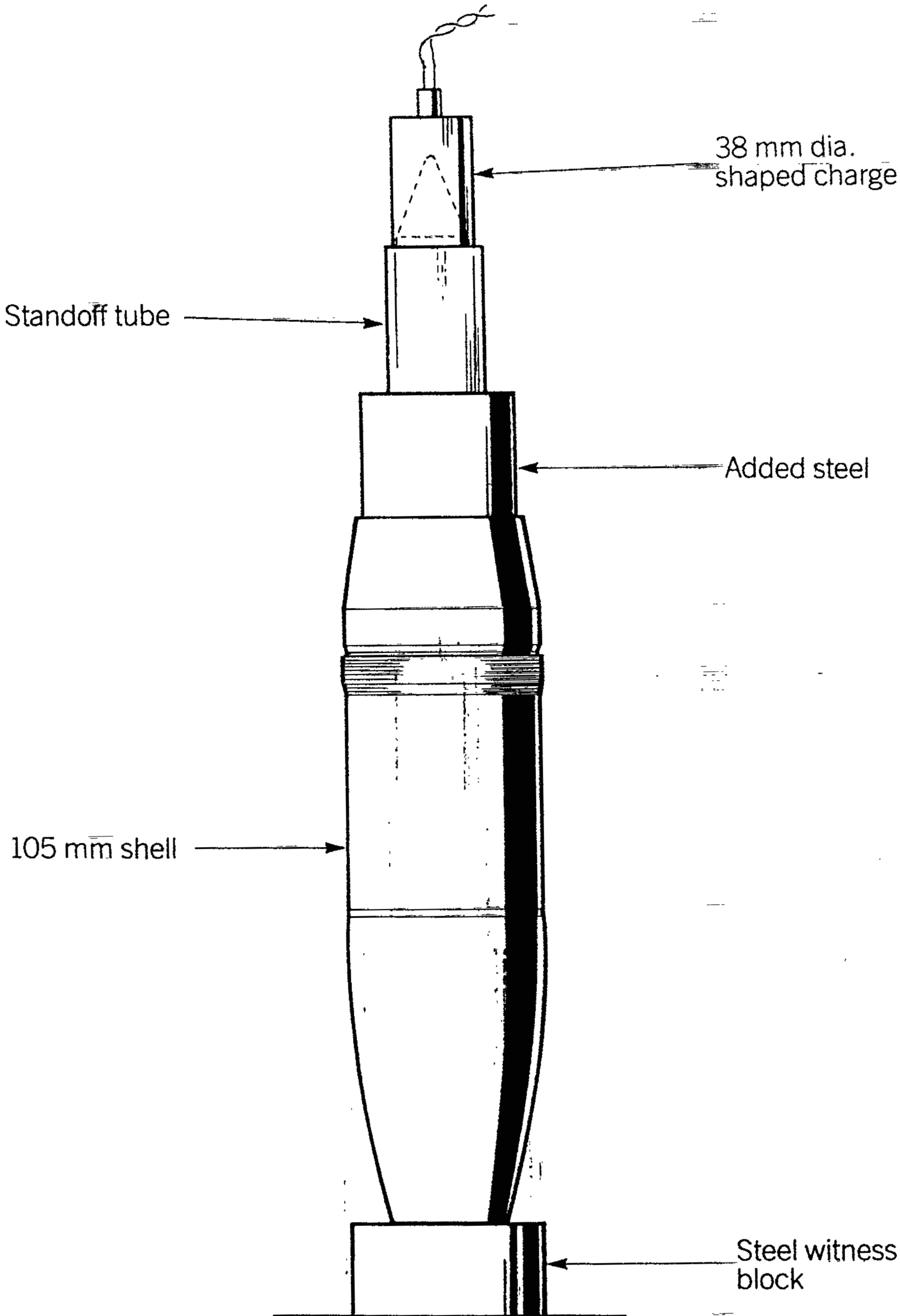

FIGURE 1.

SET-UP FOR USING A SUBCRITICAL SHAPED CHARGE JET TO VIOLENTLY DEFLAGRATE A 105 mm SHELL FILLING

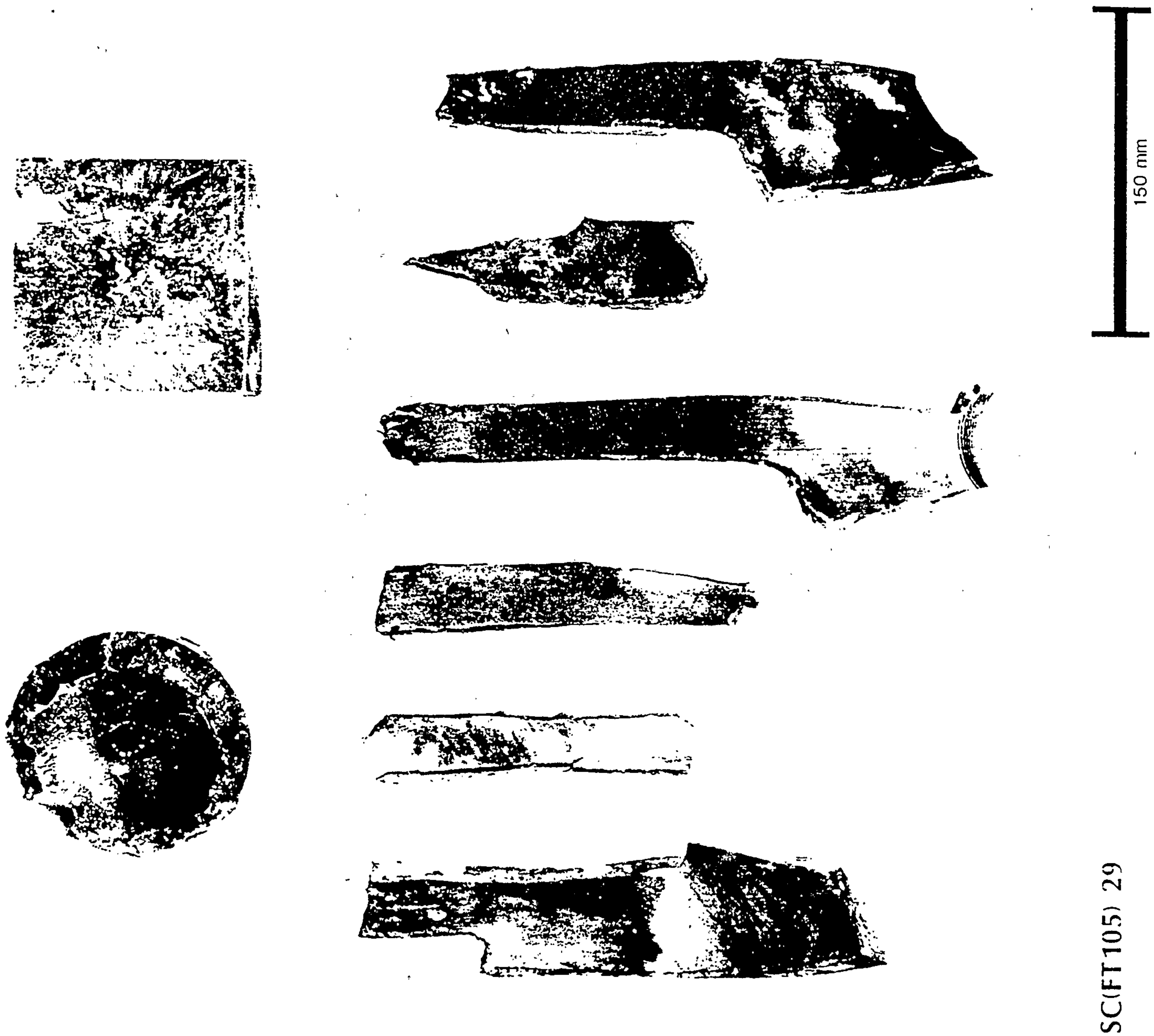

FIGURE 2

RECOVERED FRAGMENTS AND WITNESS PLATE
FROM VIOLENT DEFLAGRATION OF 105 mm COMPOSITION B
FILLED SHELL

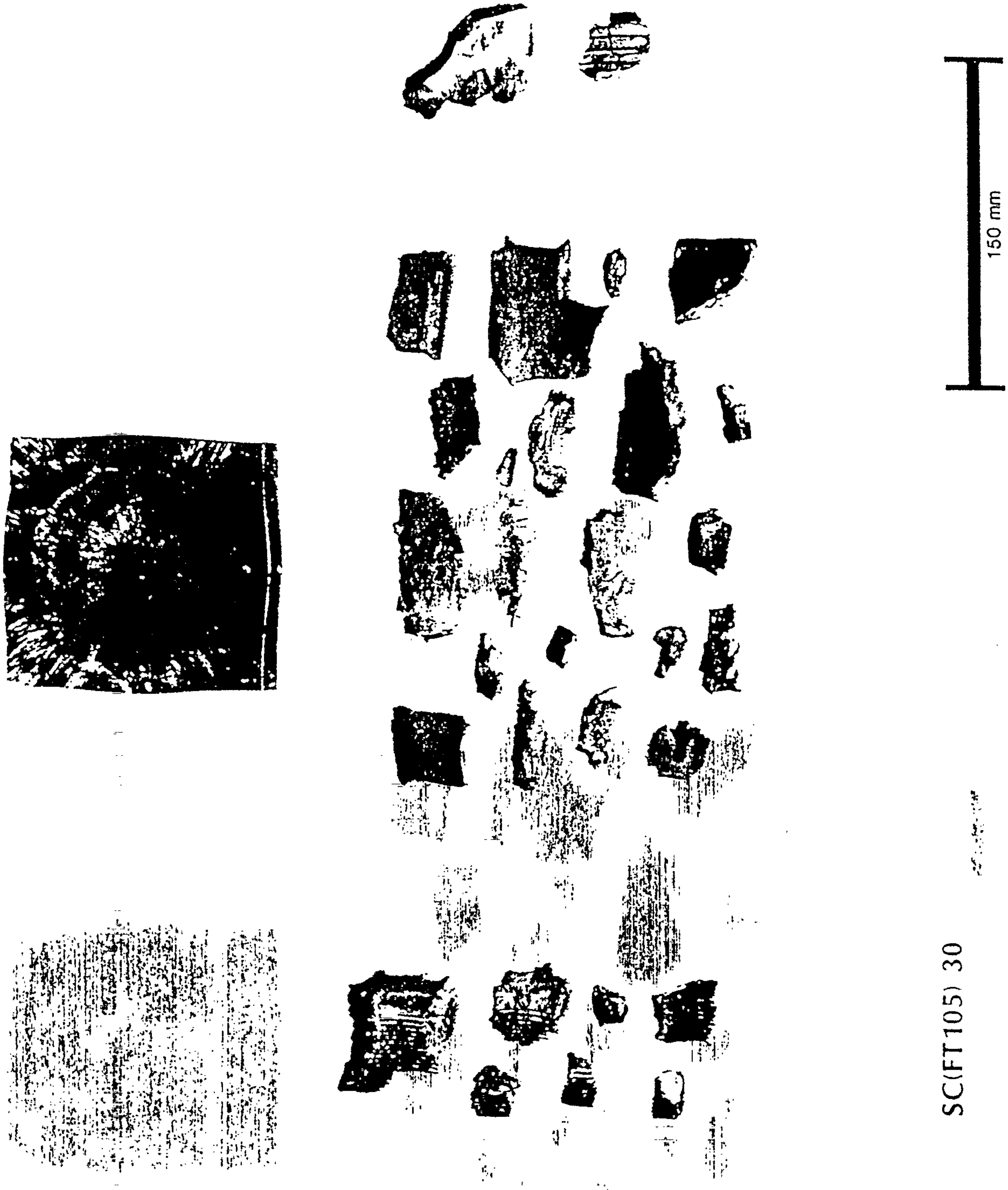

FIGURE 3

RECOVERED FRAGMENTS AND WITNESS PLATE FROM DETONATION OF 105 mm COMPOSITION B FILLED SHELL

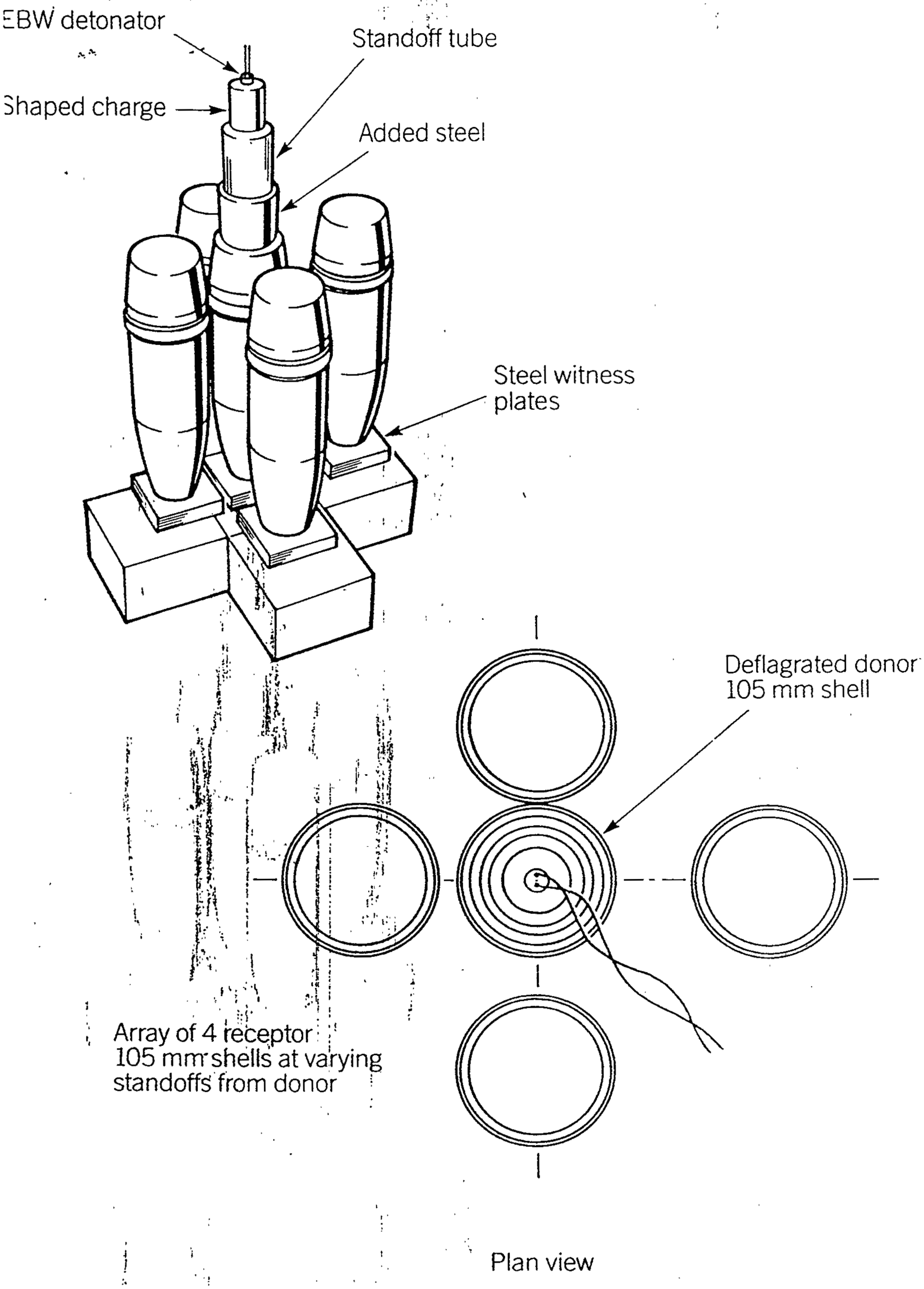

FIGURE 4.

SET-UP FOR SINGLE DEFLAGRATING DONOR - MULTIPLE ACCEPTOR TESTS

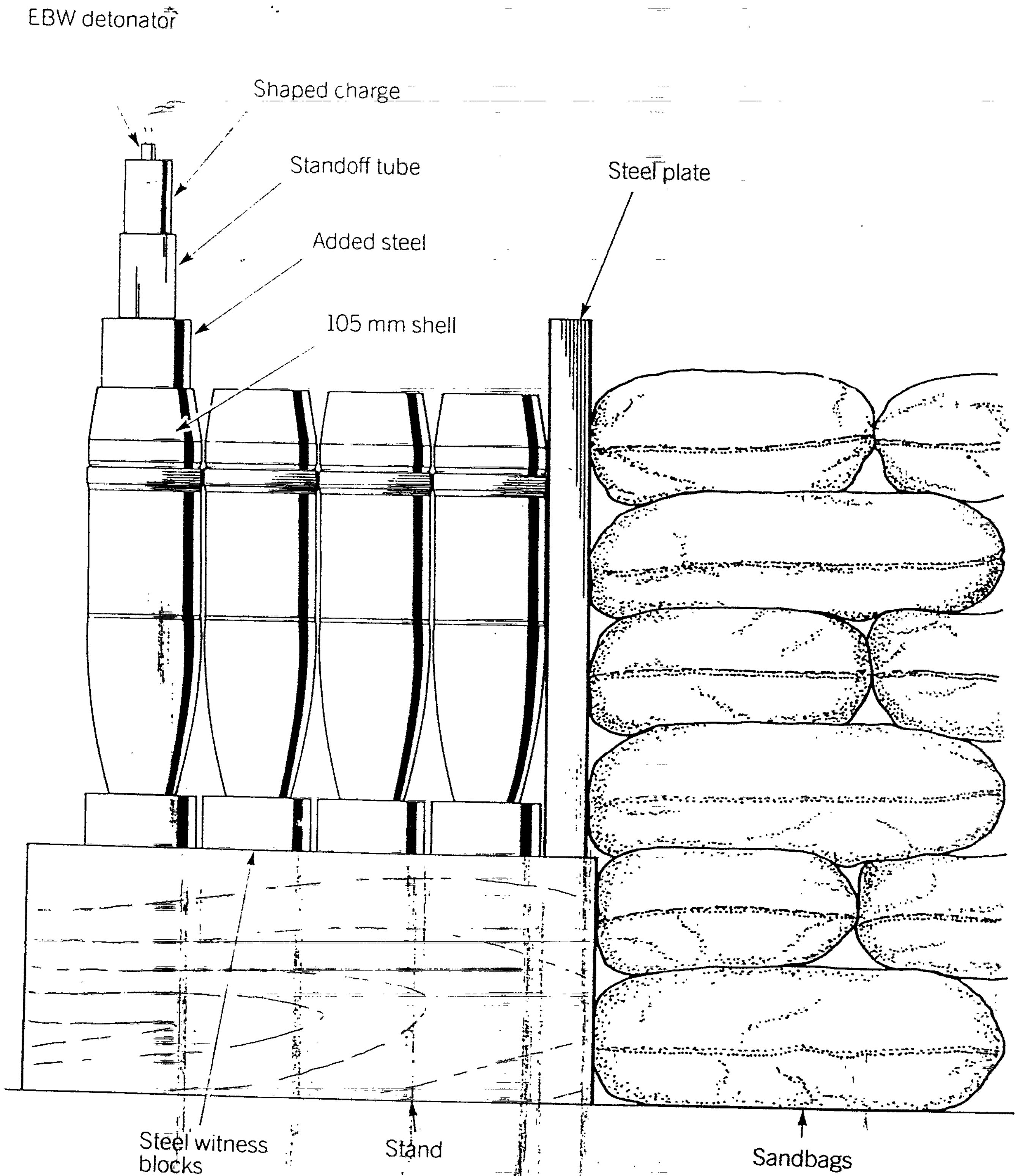

FIGURE 5

SET-UP FOR SINGLE DEFLAGRATING DONOR - ROW OF ACCEPTOR TEST

FIGURE 6

SHELL RECOVERED FORM A SINGLE DEFLAGRATING DONOR
MULTIPLE ACCEPTOR TEST

FIGURE 7

SHELL RECOVERED FORM TESTS USING ROUNDS WITH BOOSTERS
AND PLUGS REPRESENTING FUZES

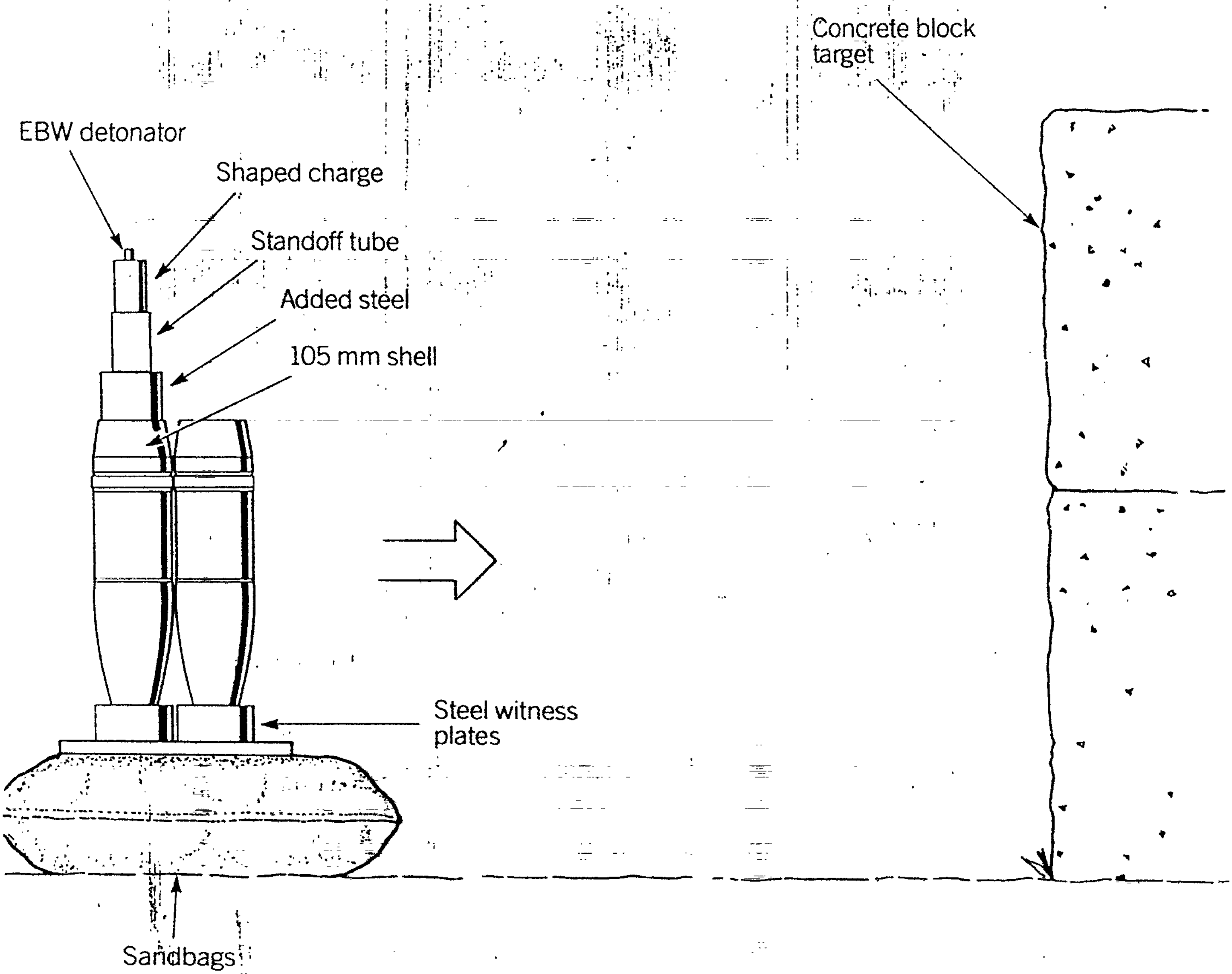

FIGURE 8.

SET-UP FOR ACCEPTOR SHELL PROJECTION AND IMPACT ON A HARD SURFACE

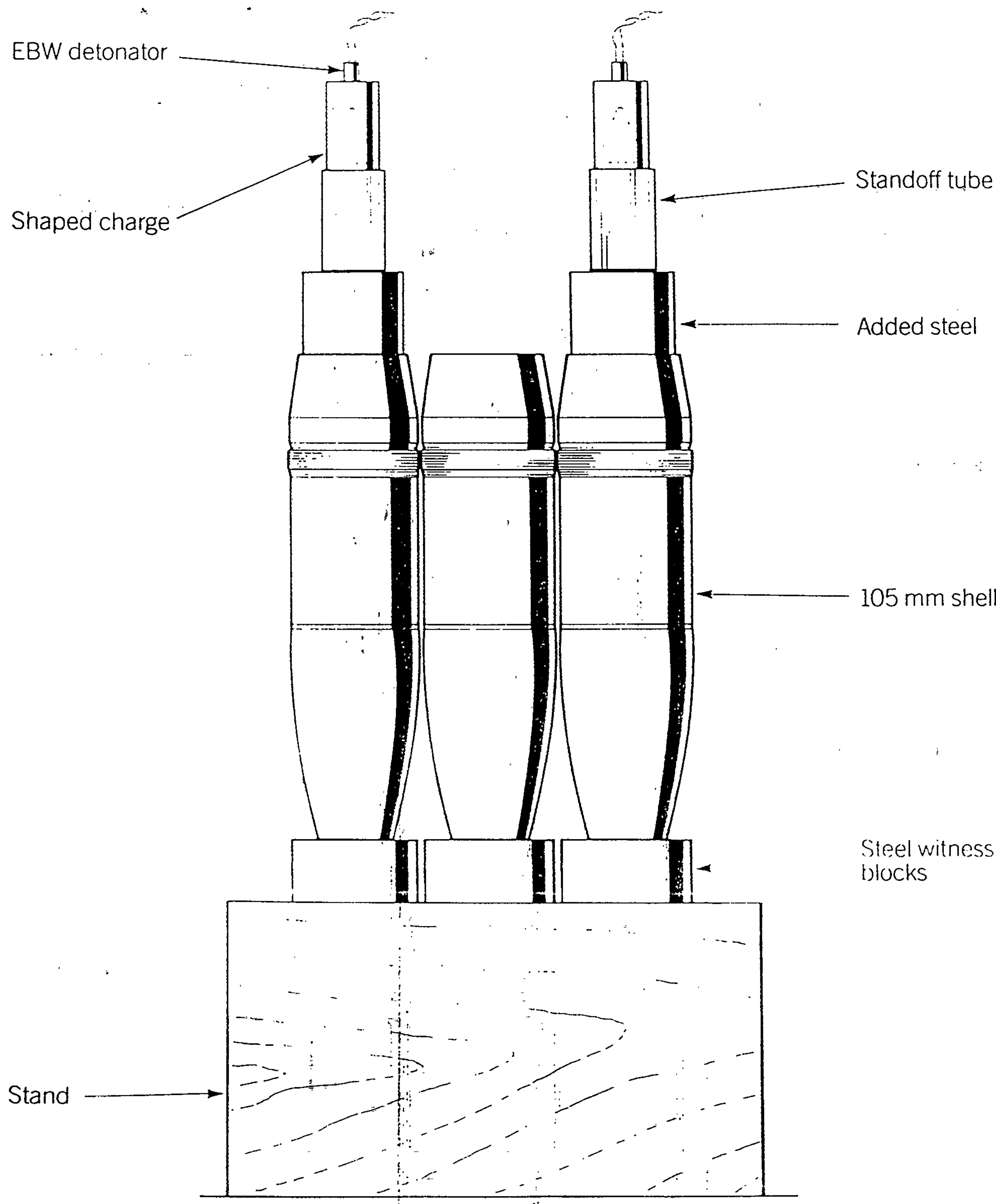

FIGURE 9.

SET-UP FOR SINGLE ACCEPTOR SIMULTANEOUSLY IMPACTED BY TWO DEFLAGRATING DONOR ROUNDS

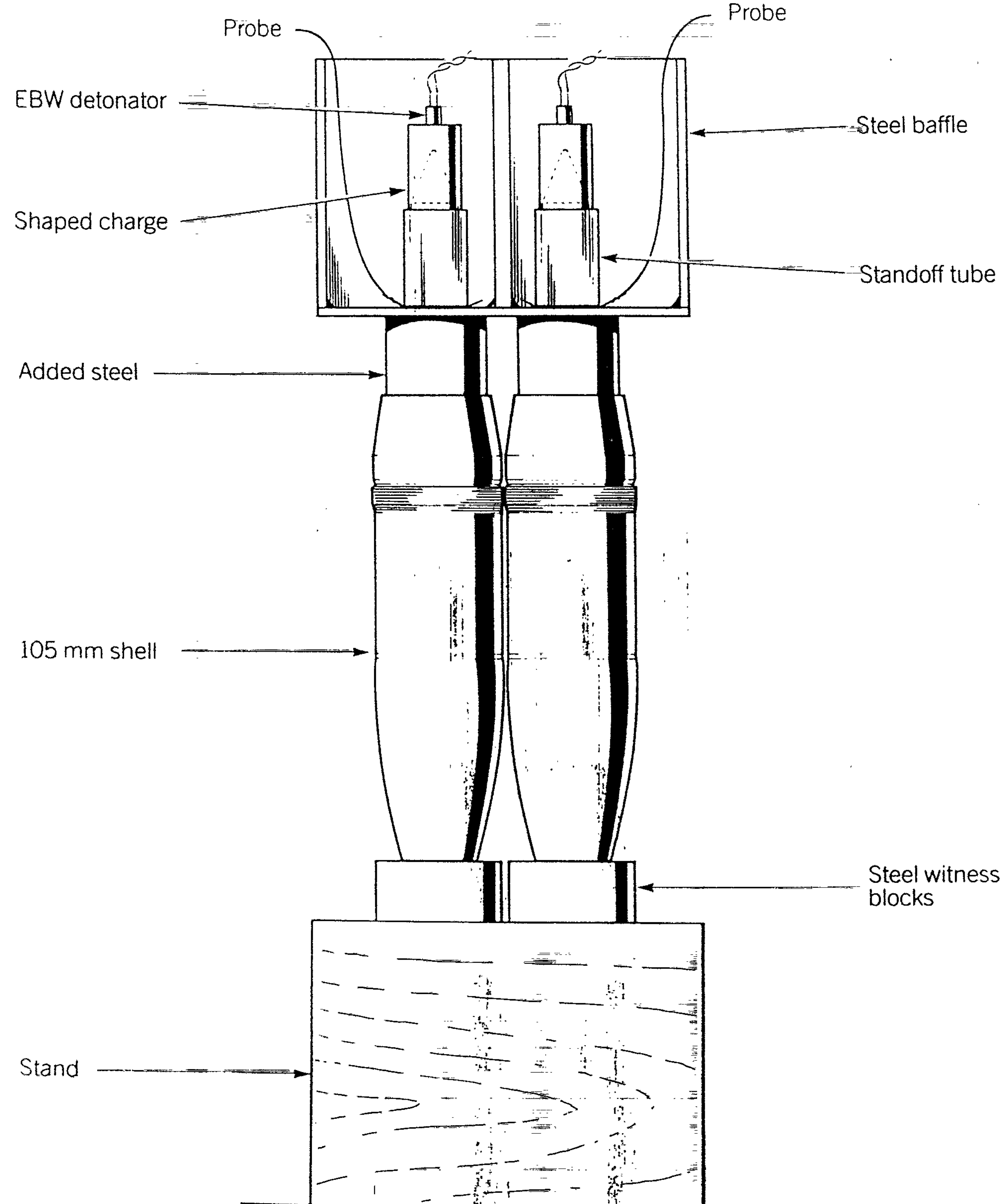

FIGURE 10.

SET-UP FOR THE DEFLAGRATION OF TWO SHELL AT A PREDETERMINED TIME INTERVAL

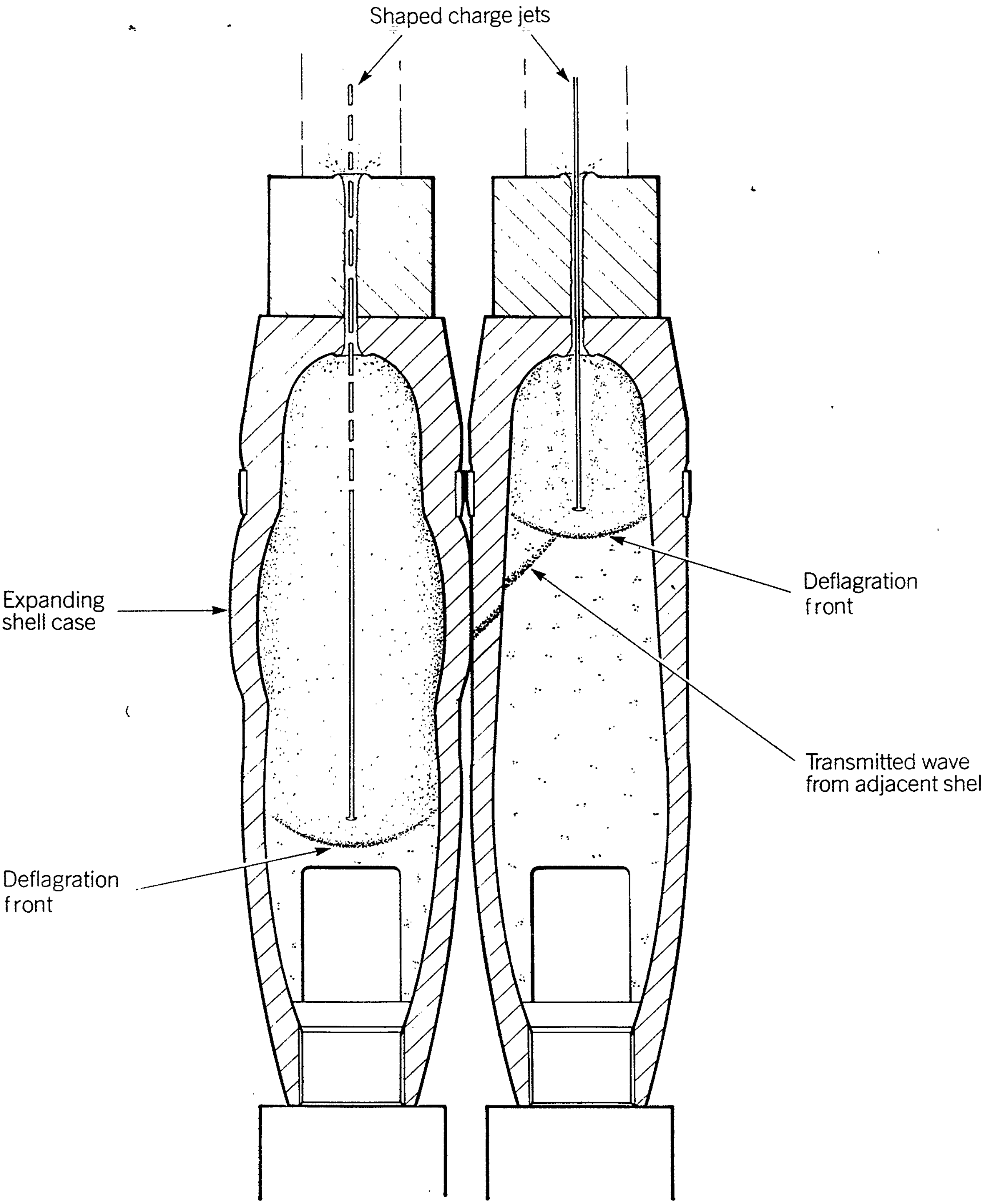

FIGURE 11.

ILLUSTRATION OF DEFLAGRATING SHELL INTERACTION